area affected. This condition improved very slowly; some highways were not opened to traffic until the end of February. In the vicinity of Sheboygan automobiles were not able to get through until the last week in March.

The interests most seriously affected by the storm, however, were the overhead wire companies. In southern and southeastern Wisconsin the precipitation began on February 3 as a light misting rain which turned to sleet and snow during the night, the temperature being slightly below the freezing point. All exposed objects were covered with glaze. In Milwaukee the coating of ice averaged about $\frac{3}{16}$ inch in thickness, but the telegraph and telephone companies report that at some other points the coating of ice on wires was $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. This ice together with the high winds caused the breakage of large numbers of telegraph and telephone poles and the prostration of many miles of wire. One company alone reported 924 poles broken, 480 miles of wire destroyed, 11,000 wire breaks, and 3,800 miles of wire to be repulled and retied to insulators. Their monetary loss was $172,000.

Because of broken wires, etc., the toll-line circuits of the telephone companies began to fail soon after midnight February 3–4, and most of them were out of order by 7 a. m. the 4th. Over most of these lines service was restored by the afternoon of the 9th, but in several localities it was interrupted for 10 days, and one of the larger companies expected that permanent repairs would not be completed until May 1.

From all available data it is estimated that the actual property loss from the storm was approximately $231,000, but the economic loss from delayed traffic of all kinds was much greater.

TORNADO IN NORTH TEXAS ON APRIL 3, 1924 [1]

A tornado was observed in Denton County, Tex., near the village of Justin about 4 p. m. April 3, 1924. It moved thence in an east-southeast direction through the northeast corner of Dallas County, the northern end of the adjoining county of Kaufman and was last observed about a mile southwest of Edgewood in Van Zandt County, having traveled a distance of about 80 miles in four hours. The tornado passed over a thinly settled district and for a part of its course the funnel cloud was not in direct connection with the ground. One person was killed and 14 injured and property loss of about $40,000 was sustained.

The meteorological conditions at the Dallas Weather Bureau station, when the tornado passed to the eastward about 12 miles directly north of the station, were not unusual or striking in any respect. The barometer fell from 29.88 inches at 8 a. m. 75th meridian time to 29.72 inches at 5:45 p. m. and then rose sharply 0.03 inch.

Hail fell in the path of the tornado in Denton, Rockwall, and Dallas Counties. There was but little thunder and lightning. The width of the tornado's path was about 1,000 feet and that of the hail fall from $\frac{1}{2}$ to 2 miles.

The usual number of freaks, such as straws being driven into wood, etc., were observed.

[1] Condensed from a report by J. L. Cline, Meteorologist, Weather Bureau Office, Dallas, Tex.

NOTE ON PARTIAL CORRELATION [1]

551.501

By EDGAR W. WOOLARD

At the time that Doctor Walker commenced his researches on seasonal correlations [2], the modern form of the theory of multiple linear correlation was new [3], and in large part he developed his own notation and methods. Walker's method of deriving the total correlation coefficient and the regression equation differs from that expounded in the textbooks of statistics, yet it apparently entails less arithmetical labor, and should be more widely known than it is.

If a variable quantity X_1 depends upon a number of other variable quantities $X_2, X_3, \ldots . X_k$, then we may look upon the successive variations of X_1 from its arithmetic mean as made up of (1) portions due to the variations of X_2 from its arithmetic mean, and (2) remainders, independent of X_2, due to the variations in $X_3, \ldots .. X_k$, and more or less of the nature of accidental errors. Under these circumstances, if we assume a linear relation between the variations x_1 from the mean of X_1 and the variations x_2 from the mean of X_2, the Theory of Least Squares gives for the "best" representation of the relationship.

$$x_1 = r\frac{\sigma_1}{\sigma_2}x_2 \qquad (1)$$

in which the so-called correlation coefficient

$$r = \frac{\Sigma(x_1x_2)}{N\sigma_1\sigma_2} \qquad (2)$$

expresses the proportionate extent to which the variations in X_1 are determined by, or related to, those of X_2. Similarly, if we wish to determine the extent to which the variations in X_1 are due to those in $X_2, X_3, \cdots X_n$ jointly, exclusive of the effects of $X_{n+1}, X_{n+2}, \cdots$, we have, assuming a linear relation

$$x_1 = a_{12}x_2 + a_{13}x_3 + \cdots\cdot + a_{1n}x_n, \qquad (3)$$

where, in the case of four variables for example, as Walker has shown

$$a_{12} = \frac{\sigma_1\{r_{12}(1-r^2_{34}) + r_{13}(r_{24}r_{34} - r_{23}) + r_{14}(r_{23}r_{34} - r_{24})\}}{\sigma_2\{1 - r^2_{23} - r^2_{24} - r^2_{34} + 2r_{23}r_{34}r_{34}\}}, \text{etc.}, \qquad (4)$$

while the "effective correlation coefficient" is

$$m = \frac{1}{\sigma_1}\sqrt{[a_{12}\sigma_2 r_{12}\sigma_1 + a_{13}\sigma_3 r_{13}\sigma_1 + a_{14}\sigma_4 r_{14}\sigma_1]}, \qquad (5)$$

and expresses the proportionate extent to which the variations in X_1 are governed by those in X_2, X_3, X_4.

[1] Presented as part of the discussion on Dr. G. T. Walker's method of making monsoon rain forecasts, Weather Bureau staff meeting of Apr. 16, 1924.

[2] G. T. Walker. Correlations in Seasonal Variations of Climate, *Mem. Ind. Metl. Dept.*, Vol. XX, pt. 6, 1909; Correlation in Seasonal Variations of Weather, II, *Mem. Ind. Metl. Dept.*, XXI, pt. 2, 1910; III, XXI, 9, 1914; IV, XXI, 10, 1915; V, XXI, 11, 1915; VI, XXI, 12, 1915; VII, XXIII, 2, 1922; VIII, XXIV, 4, 1923.

[3] G. U. Yule. On the Theory of Correlation for any Number of Variables, Treated by a new System of Notation. *Proc. Roy. Soc.*, A79, 182–193, 1907.

Now, in the form in which the theory has been developed by Pearson and Yule, the "total correlation coefficient," showing the combined effect of all the factors upon X_1, is

$$R_{1.234\cdots n}=\sqrt{[1-(1-r^2_{12})(1-r^2_{13.2})(1-r^2_{14.23})\cdots(1-r^2_{1n.234\cdots(n-1)})]} \quad (6)$$

in which

$$r_{12.34\cdots i}=\frac{r_{12.34\cdots(i-1)}-(r_{1i.34\cdots(i-1)})(r_{2i.34\cdots(i-1)})}{\sqrt{1-(r^2_{1i.34\cdots(i-1)})(1-r^2_{2i.34\cdots(i-1)})}} \quad (7)$$

is the net coefficient of correlation between X_1 and X_2 after the effects of X_3, ... X_i have been eliminated. The regression equation (3) becomes

$$x_1=b_{12.34\cdots n}x_2+b_{13.24\cdots n}x_3+\cdots+b_{1n.23\cdots(n-1)}x_n, \quad (8)$$

where

$$b_{12.34\cdots n}=r_{12.34\cdots n}\frac{\sigma_{1.34\cdots n}}{\sigma_{2.34\cdots n}}, \text{ etc.,} \quad (9)$$

$$\sigma_{1.34\cdots n}=\sigma_1\sqrt{(1-r^2_{13})(1-r^2_{14.3})\cdots(1-r^2_{1n.34\cdots(n-1)})}. \quad (10)$$

Walker has shown the identity of his m and Yule's $R_{1.234\cdots n}$; and it is not difficult to show that the numerical values of the coefficients given by (4) and (9) are identical, but are much more easily obtained by the following device due to Walker:

Write (3) in the form

$$\frac{x_1}{\sigma_1}=c_2\frac{x_2}{\sigma_2}+c_3\frac{x_3}{\sigma_3}+\cdots+c_n\frac{x_n}{\sigma} \quad (11)$$

by replacing a_{1i} with $c_i\frac{\sigma_1}{\sigma_i}$; the ratios of the actual departures from the averages to the standard deviations, x_i/σ_i, Walker calls the "proportional departures." Then it may be shown that

$$m^2=c_2^2+c_3^2+c_4^2+\cdots+c_n^2+2c_2c_3r_{23}+2c_2c_4r_{24}+\cdots+2c_3c_4r_{34}+\cdots \quad (12)$$

Furthermore, since

$$x_i=r_{ij}\frac{\sigma_i}{\sigma_j}x_j, \quad (13)$$

we have

$$\begin{aligned} r_{12}&=c_2r_{22}+c_3r_{23}+c_4r_{24}+\cdots+c_nr_{2n},\\ r_{13}&=c_2r_{23}+c_3r_{33}+c_4r_{34}+\cdots c_nr_{3n},\\ &\cdots\cdots\cdots\\ r_{1n}&=c_2r_{2n}+c_3r_{3n}+c_4r_{4n}+\cdots+c_nr_{nn}, \end{aligned} \quad (14)$$

$(n-1)$ simultaneous linear equations from which the c's may be found, by employing any of the well known shortened methods of solving such a set of equations.[4]

Thus the total correlation coefficient and the regression equation may be found without computing any of the great number of net correlations required by the usual methods.

[4] See E. T. Whittaker and G. Robinson. *The Calculus of Observations*, London, 1924. Chap. V, and *Arts*, 121, 117.

NOTES, ABSTRACTS, AND REVIEWS

FOUR WIRELESS STATIONS TO BE ERECTED IN GREENLAND

(Excerpts from report by J. D. Price, United States minister, Copenhagen, Denmark, March 10, 1924)

The parliamentary committee on finance has now granted an appropriation of about 700,000 crowns [$170,327.00] for the erection of four wireless stations (of the Danish Poulsen system) on Greenland, which Continent will thus be enabled to share directly in world intercourse. The stations are also expected to prove of both direct and indirect value to commerce and science, especially to the international weather service.

The stations, which are to be constructed by the Danish Radio Co. of Danish material supplied by Skoumann & Petersen and other Danish firms, are to be located at Angmagsalik (on the eastern coast), Julianehaab (southern point of Cape Farewell), Godhavn and Godthaab (both on the western coast). The main station is to be at Julianehaab and is to be of sufficient capacity under normal conditions to correspond with the present stations at Reykjavik (Iceland) and Thorshavn (Faeroes), and under especially favorable conditions, to reach the main Danish station at Lyngby (near Copenhagen) and the European Continent.

Three of the stations are to be adapted for telegraphic communication with continuous waves, and to be fitted with spark transmitters for local correspondence.

FRANK HAGAR BIGELOW, 1851-1924

Professor Bigelow was born at Concord, Mass., of sturdy New England antislavery stock. He was graduated from Harvard in the class of 1873, and soon thereafter entered the Episcopal ministry. The development of an affection of the lungs cut short his ministerial career, although he was in close affiliation with the church throughout his whole life. In seeking a dry climate his attention was directed to Argentina where a former Harvard graduate, the late Dr. B. A. Gould, was engaged in astronomical work. Bigelow served as assistant to Doctor Gould, 1873–1876 and again 1881–1883. Returning from South America he was successively professor of mathematics, Racine College, 1884–1889 and assistant in the Nautical Almanac Office, 1889–1891, member of United States Eclipse expeditions, to West Africa, 1889; Newberry, S. C., 1900; Spain, 1905. He was appointed professor of meteorology in the United States Weather Bureau in October, 1891, and resigned in 1910. He spent the next 11 years with the meteorological service of Argentina, being stationed for the most part at Cordoba and Pilar. On his retirement from that service in 1921 he went first to Marseilles, France, and later to London. Finally, he went to Vienna where he died of pneumonia on March 2, 1924. His wife survived him but a few days and succumbed to the same disease

Professor Bigelow was by nature a student-investigator and was possessed of a seemingly inexhaustible supply of energy backed by the will to pursue any subject that he might take up until the end.

Perhaps his outstanding piece of work while with the Weather Bureau was his contribution to the subject of the general circulation of the atmosphere in a series of related papers that were published in the MONTHLY WEATHER REVIEW, 1902–1906. Previous to the writing of these papers he had finished two ponderous volumes, the first on the international cloud observations, and the second on the barometry of the United States. Both